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Artificial Propagation of Lake Sturgeon Acipenser fulvescens (Rafinesque), Under Hatchery Conditions in Michigan

Eric Robert Anderson

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ARTIFICIAL PROPAGATION OF LAKE STURGEON *ACIPENSER FULVESCENS* (RAFINESQUE), UNDER HATCHERY CONDITIONS IN MICHIGAN[1]

Eric Robert Anderson

[1]This is a reprint of a thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Fisheries, in the School of Natural Resources, The University of Michigan, 1984.

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A thesis submitted in partial fulfillment
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Master of Science
School of Natural Resources
The University of Michigan
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Committee members

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ABSTRACT

Eggs and milt were collected from spawning adult lake sturgeon (Acipenser fulvescens Rafinesque) from the upper Black River, Cheboygan County, Michigan, on 13 May 1983. Eggs, obtained by cesarean-section, were fertilized by the dry method, using milt stripped from males and collected by syringe. Lake sturgeon eggs collected from the Fox River in Winnebago County, Wisconsin, were fertilized and donated by the Wisconsin Department of Natural Resources. Fertilized eggs were incubated in standard McDonald hatching jars.

Artificial and natural diets were presented to groups of experimental sturgeon, and survival and growth were measured for each group. Natural diets were zooplankton and aquatic annelids; artificial diets were Biodiet and Oregon Moist Pellets. Both direct and weaned feeding were tested.

Sturgeon fed natural diets throughout the study showed highest survival (45-90%) and growth rates (approximately 7.6 mm/week) for all groups tested. Michigan and Wisconsin sturgeon fed natural diets showed similar mortalities during the 9-week study, however, Wisconsin fish showed significantly higher growth rates (8.18 mm/week) than Michigan sturgeon (6.92 mm/week). In contrast, fish fed artificial diets did not survive 9 weeks and had decreased growth rates (approximately 4.7 mm/week). The exception was one weaned group fed Biodiet, which showed growth rates similar to fish fed natural diets, but with a survival of only 3.7%.

INTRODUCTION

Lake sturgeon (*Acipenser fulvescens* Rafinesque) were once abundant throughout the entire Great Lakes region. Factors such as overfishing, poor water quality, and the damming of their spawning rivers have been largely responsible for their decline (Harkness and Dymond 1961; Scott and Crossman 1973). The lake sturgeon is currently classified as threatened (1976) by the Michigan Department of Natural Resources and rare by the United States Department of Interior (1977).

During the late 1900's, several attempts were made to propagate the lake sturgeon artificially in the Great Lakes region (Post 1890; Meehan 1909; Leach 1920). Early attempts were largely unsuccessful for several reasons (reviewed by Binkowski 1980). Locating ripe males and females at the same time was perhaps the greatest problem. Also, males were reported to be more abundant than females during the spawning migrations. Stripping the sturgeon of eggs by the conventional pressure method was generally unsuccessful. Further, obtaining a successful hatch was also a problem, due to the adhesiveness and susceptibility of eggs to fungal infestations. If eggs were successfully hatched, the fry soon died as no suitable food source was known (Leach 1920). Attempts at culturing the lake sturgeon were largely discontinued from 1926 to 1979, when Wisconsin Department of Natural Resources biologists successfully reared lake sturgeon to a plantable size (Czeskleba 1979).

The purpose of this study was to evaluate several diets and feeding techniques for survival and growth of young sturgeon. The diets tested were two artificial diets, Biodiet and Oregon Moist Pellets (OMP), and a natural diet. The feeding methods tested were weaned and direct feeding. In addition, several other ancillary objectives related to culture of sturgeon were: (1) locate a spawning population in the State of Michigan where adults could be easily captured, (2) collect eggs and milt from spawning adults without harming them, due to their rare and threatened status in Michigan; (3) work out the proper fertilization techniques, (4) hatch the eggs in a hatchery and rear the young to a plantable size.

CULTURAL METHODS

Capture of adult lake sturgeon

Adult lake sturgeon were captured on their spawning migration during the spring of 1983 using large, long-handled dip nets. The sturgeon were captured on the upper Black River, a tributary of Black Lake, Cheboygan County, Michigan. The sturgeon were captured on 13 May 1983 at the first set of rapids directly below Kleber Dam (Fig. 1). Water temperature at the time of capture was 16.1 C. The Wolverine Power Supply Cooperative retained the water behind the dam to make the sturgeon more vulnerable to our nets. Lowering the water level did not appear to have an effect on their spawning activity. Males and females were easily distinguishable in the shallow, clear water. Females were

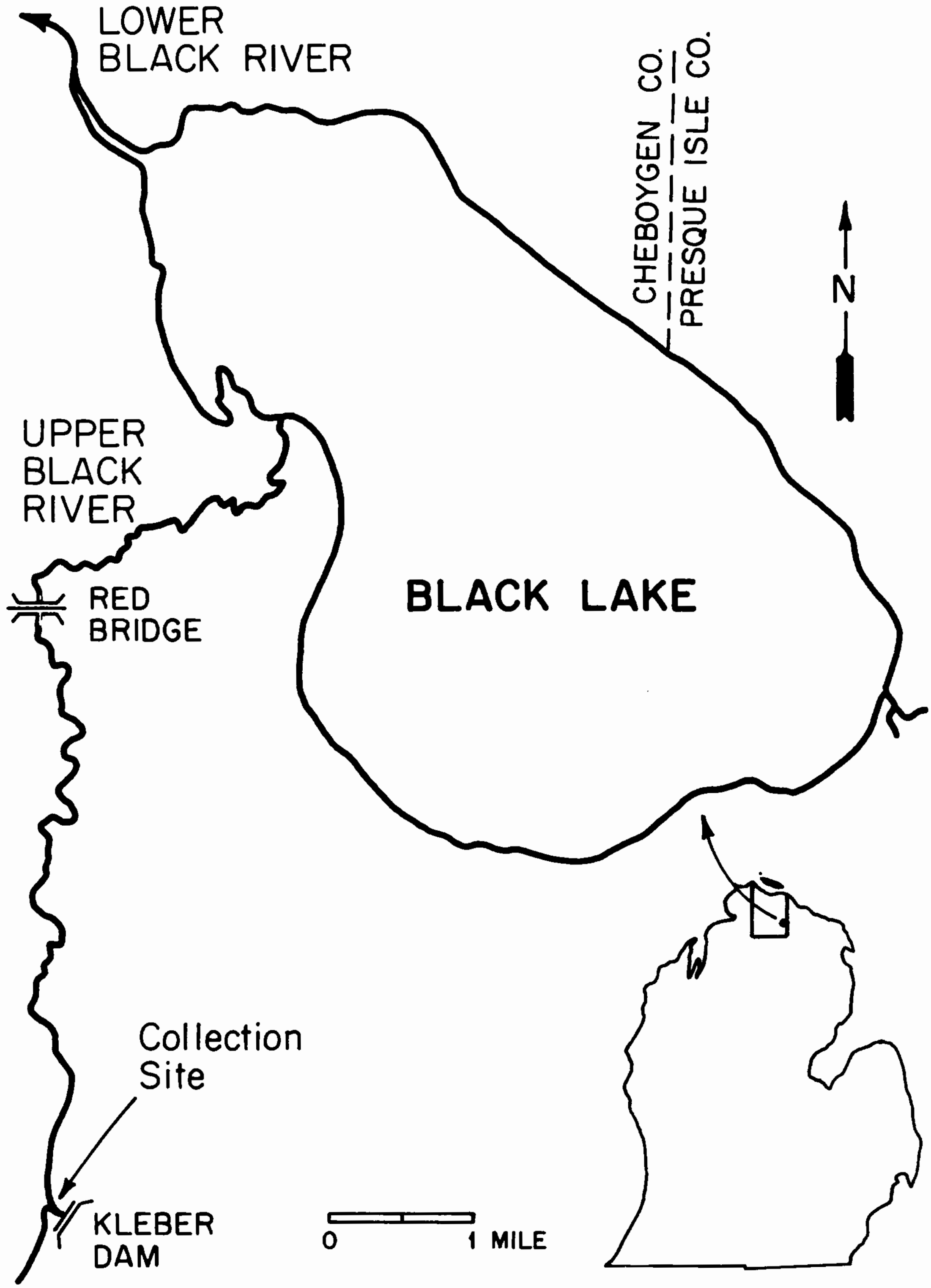

Figure 1. Collection site for lake sturgeon on the upper Black River, Cheboygan County, Michigan, 1983.

considerably larger than males, and were typically surrounded by two to three males. Once a sturgeon was netted, it was brought to shore and transferred to a stretcher for collection of eggs or milt.

Collection of milt

The male sturgeon were processed first since it is possible to store milt "dry" on ice in graduated cylinders for several hours (Ginzburg 1972). Once a fish was netted, it was taken to shore and placed ventral side up in the stretcher, its head inserted into a sewn-in burlap sack to calm the fish. The burlap sack was kept wet at all times to prevent the gills from becoming desiccated. The stretcher was supported by two saw horses to prevent movement of the fish and to raise the stretcher to a comfortable working height. The area surrounding the vent was dried off completely. Milt, released by gently stripping the fish, was drawn into a 50-cc syringe. After three to four strippings, the milt was transferred to a dry graduated cylinder and stored in an ice chest until needed. The sturgeon was then returned to the river unharmed. Care was taken to insure that no water came into contact with the milt at any state prior to fertilization, as the milt becomes activated in water. Milt was collected from four males and held on ice for approximately 30 minutes before use.

Egg collection

On 13 May 1983, 2.1 L of eggs (39,900) were collected from two of four sturgeon, spawning below Kleber Dam. As a back-up egg source for this study, the Wisconsin Department of Natural Resources donated 1.9 L of lake sturgeon eggs (36,100). The Wisconsin eggs were collected from adults captured below Eureka Dam, the Fox River, during late April. The eggs were counted using the Von Bayer method (Leitritz and Lewis 1976). Both the Wisconsin and Michigan sturgeon eggs measured 19,000/L.

Four Michigan female sturgeon were captured and evaluated for ripeness by palpation of the abdomen and visual inspection of their eggs. Usually once a female sturgeon was handled, the sphincter muscles surrounding the vent contracted, making stripping impossible. As a result, a cesarean-section technique was used to remove eggs without harming the fish. The technique was developed in California for the white sturgeon (*Acipenser transmontanus*), and later applied to the lake sturgeon in Wisconsin (Binkowski and Czeskleba 1980).

Once a suitable fish was captured, it was placed in the stretcher and the area surrounding the vent was dried, as the eggs also become activated in water. Using a heavy surgical scalpel, a 3.8 to 5.0-cm incision was made approximately 10 cm anterior and to the left of the vent. Of the four female sturgeon cesarean-sectioned, only minimal bleeding was observed in one female. Once the incision was made, the fish was rotated dorsally allowing the eggs to flow from the incision into a 12-quart stainless steel mixing bowl. If the eggs were ripe, they flowed freely from the incision. Care was taken to keep water from entering the stainless steel bowl before fertilization. When the desired amount of eggs was collected, the incision was closed with 3-0 dissolving suture material. A cutting needle was used, as the sturgeon's epidermis is very tough. A suture clamp or needle holder was used to properly manipulate the needle. A standard mattress pattern was chosen using 1/8-inch spaces between sutures. Once the incision was closed properly, the sturgeon was returned to the water. Usually a brief recovery period was necessary, holding the fish facing into the current. Previous telemetry studies, conducted by the Wisconsin Department of Natural Resources, have shown no mortality associated with the cesarean-section technique. In all cases the incision healed (Folz, et al. 1983)

Fertilization of the eggs

Once eggs and milt were collected, the fertilization process was begun as soon as possible, usually within 5 minutes. The dry method of fertilization was used. Milt was added "dry", directly to the eggs contained in the bowl and mixed for approximately 10 seconds. River water was then stirred into the mixed eggs and milt, and the solution was allowed to sit for several minutes. At approximately 4 minutes post-fertilization, sturgeon eggs become extremely adhesive, clumping together and making them difficult to handle. To alleviate this problem, bentonite clay powder was added at that time. The bentonite clay powder was suspended in water to a "milk-shake" consistency prior to use. Two cups of the bentonite mixture were used per 12-quart pan. Once added, the mixture was stirred gently by hand for about 10 minutes, or until the adhesiveness was eliminated. The eggs were then allowed to sit for approximately 1 hour to water harden, and were then rinsed clean, packed in plastic bags within styrofoam coolers, and transported to the hatchery.

Incubation of the eggs

The fertilized eggs were transported from the Black River site to the Wolf Lake State Fish Hatchery, near Kalamazoo, for hatching and rearing. The water temperature was 16.1 C on-site and did not fluctuate during transport to the hatchery.

Standard McDonald hatching jars were used for incubation of both the Wisconsin and Michigan sturgeon eggs. Several days prior to hatching, the Michigan eggs were placed in vertical-flow incubators to contain larvae once they hatched, while Wisconsin eggs were left in the hatching jars. Flow rates through the McDonald incubators were held at 7.5 L per minute, while the flow was reduced to 3.8 L per minute when the vertical-flow incubators were in use. The water temperature was held constant at 15.0 C and the eggs began hatching in 9 days. Hatching was completed within 24 hours.

During the incubation period, the eggs were treated with formalin on alternate days for 15 minutes to prevent fungal infection. During the latter part of incubation, formalin treatments of the Michigan eggs were discontinued due to sucker fry being held within the same water system. As a result, approximately 28% of the eggs were lost to fungus. The Wisconsin eggs also were attacked by fungus and approximately 24% of these eggs were lost.

When removed from the female sturgeon, most of the eggs were very dark in color (green-black) with a small buff colored spot (the germinal vesicle) visible on one pole. Once eggs were water hardened, they began to change color, progressively turning lighter until hatching, when they were almost clear. After the eggs cleared, hatching usually occurred within 36 hours. Approximately 76% (27,500) of the Wisconsin eggs and 72% (28,600) of the Michigan eggs hatched. Upon hatching, the larvae were transferred from the vertical-flow incubators into holding tanks.

<u>Hatching</u>

At hatching the lake sturgeon larvae were approximately 1.0 cm in length. Some of the larvae had developed gills and eyes at time of hatching while others had not. From hatching until yolk-sac absorption, the larvae swam constantly, and were very negatively phototactic. Approximately 20 days post-hatch their behavior changed and they became positively phototactic and less active. This behavior pattern coincided with yolk-sac absorption and exogenous feeding.

Feeding

Prior to the diet study, the fry were fed zooplankton, mainly Daphnia pulex and various stages of copepods, first introduced several days prior to yolk-sac absorption. Zooplankton were collected twice daily from a local lake with a plankton net. During the first 10 days of feeding, the zooplankton was screened through Nitex (333 microns) to permit only the smallest zooplankton to enter the tanks. Sturgeon were dissected daily to determine the onset of exogenous feeding. The yolk sac was fully absorbed at 15-19 days post-hatch. At 23 days post-hatch, approximately 40% of the fry examined had begun to feed. At 28 days 70% of the sturgeon examined had zooplankton in their stomachs. After the 10-day screening period, zooplankton were added directly into the tanks, as the fry were large enough to feed on the largest zooplankton. The fry fed most actively during the evening hours, and were often observed feeding from the surface and water column. Nitex screens were used at the ends of the raceways to prevent the zooplankton from being washed out of tanks. After the sturgeon were feeding well on the zooplankton, the diet study was started. At approximately 16 days post-hatch (Michigan sturgeon), and 31 days post-hatch (Wisconsin sturgeon) the fry were transferred to new tanks for the diet study.

EXPERIMENTAL METHODS

The fiberglass tanks used were 2.7 m in length, 51 cm in width, and had a depth of 30 cm. Each tank was set up as a flow-through system, and held 1,100 L of heated spring water. The temperature was held constant during the study at 19.4 C with a flow rate of 7.5 L/min/tank.

On 5 June, the surviving fry were counted into the tanks in preparation for the diet study which began the following day. Michigan and Wisconsin sturgeon were kept separate during the study. Three samples of 2,000 sturgeon each were randomly collected to determine average weight so that handling time of fry would be minimal. Eighteen tanks, containing approximately 2,000 sturgeon fry (114 g) each, were set up for the diet study.

Two artificial diets commonly used in commercial hatcheries were tested against a natural diet, and evaluated for sturgeon survival and growth. Both OMP and Biodiet are semi-moist pellets and were expected to be more palatable (acceptable) to the sturgeon than a standard dry diet. Additionally, neither diet had previously been tested on a large scale culturing lake sturgeon. Appropriate sizes of Biodiet and Oregon Moist Pellets were tested against a natural diet, composed of zooplankton and later an aquatic annelid, <u>Lumbriculus variegatus</u>. Two methods of feeding were used with the artificial diets, direct and weaned. Sturgeon that were fed under the direct method were abruptly switched to the artificial diet at the beginning of the experiment. The sturgeon being fed according to the weaned method continued on decreasing amounts of zooplankton for 15 days. OMP was used in six tanks, three weaned and three direct. Biodiet was also fed to six tanks, three weaned and three direct. The natural diet was fed to six tanks. Each tank was assigned a specific diet, and randomly assigned a position in the hatchery building. Pure cultures of Michigan or Wisconsin sturgeon were then randomly placed in each tank.

The artificial diets were presented using Loudon automatic feeders suspended above the tanks. The feed was released into the tanks at 15-minute intervals from 3:00 P.M. to 5:00 A.M., at a rate of 10 g per day per tank. Beer (1982) showed frequent night feedings enhanced acceptance of artificial pellets for white sturgeon. The artificial diets were fed to excess. The natural diet was presented twice daily, morning and evening, combining both the zooplankton and annelids, until 17 June when only worms were used. The worms provided were eaten readily, amounting to approximately 150 ml (170 g) per day to each tank initially and increased to 300 ml (340 g) per day from 15 July until 10 August. However, fish did not appear to be satiated at these levels.

Mortality (number of dead sturgeon) and water temperature were recorded daily. Length and weight of experimental fish were measured weekly. For this, 30 live sturgeon were randomly selected from each tank and anesthetized using MS-222 (1.1:10,000) for 60 seconds. The fish were measured individually to the nearest mm (total length) and weighed (as a group of 30) to the nearest g. Measurements were not taken from dead sturgeon.

Analysis

Mortality was calculated by subtracting the daily number of dead sturgeon from the total number of surviving sturgeon, dividing by the grand total and summing by weeks. The data were analyzed as a binomial distribution (daily number living or dead), expressed as percent survival (Snedecor and Cochran 1971) (Tables 1 through 3).

Length data were used to examine growth that occurred during the study. Growth rate was evaluated as the slope of the body length-time relationship based on mean values for weekly samples since growth appeared to be strongly linear for experimental fish (see also Monaco, et al. 1981). Analysis of covariance (ANCOVA) was used to examine differences in growth rates between sturgeon fed different diets and between Michigan and Wisconsin sturgeon fed natural diets. The level of significance was set at α = 0.05 for all tests. The data were analyzed using the MIDAS statistical package at The University of Michigan (Fox and Guire 1976).

A potential problem associated with this estimate of growth rate is that high mortality rates that occurred during the initial part of the study may have selectively kept smaller (starved) fish from being included in the size measurements. This may wholly account for apparent growth in lots that only survived through the initial weeks of the study, and possibly inflate growth rate estimates somewhat for the remaining lots (see Tables 4 through 9).

RESULTS

Survival

Survival, expressed here as cumulative percent survival, was greatest in the natural diet tanks (Table 1). For the Michigan sturgeon fed natural diets, survival to 9 weeks was 74.73 ± 24.54% (mean ±2 standard errors), whereas Wisconsin sturgeon had 53.77 ± 8.4% survival.

Biodiet weaned was the only artificial diet tank that had survival through the 9 weeks of the experiment (3.7%, Table 2). Most of the sturgeon that fed on artificial diets died before the fifth week of the study (Tables 2 and 3). Therefore no useful conclusions were drawn from comparisons of their survival.

Growth

Overall, the six lots of sturgeon fed natural diets grew from 26.18 mm (mean total length) and 0.07 g (mean body weight) to 84.31 mm and 2.26 g during the 9-week study period (Tables 4 and 7). The three lots of Michigan fish, initially 26.45 mm and 0.07 g, grew to 80.31 mm and 1.96 g (Tables 5 and 8). Results from analysis of covariance (ANCOVA) showed that rates of growth (in length) for these three lots were not significantly different ($P = 0.3265$;

Table 1. Percent survival (weekly) of lake sturgeon fed natural diets over 9 weeks.

Tank Source (N)	7 (MI) 2,048	11 (MI) 1,981	17 (WI) 2,002	18 (WI) 2,627	19 (WI) 2,370	20 (MI) 2,667
Week						
1	99.0	99.2	82.8	64.1	88.5	95.3
2	96.7	97.1	79.8	59.8	81.7	78.4
3	92.9	89.2	72.8	57.1	76.1	72.0
4	92.1	88.8	68.0	51.7	69.8	68.2
5	91.5	87.9	64.4	50.0	66.8	64.2
6	91.0	86.2	60.4	47.9	62.1	56.7
7	90.0	84.9	58.5	46.3	60.6	53.0
8	90.0	84.4	57.7	45.9	59.7	51.5
9	89.7	84.1	56.8	45.4	59.1	50.4

Table 2. Percent survival (weekly) of lake sturgeon fed Biodiet under weaned and direct methods.

	Biodiet (weaned)			Biodiet (direct)		
Tank Source (N)	10 (MI) 2,003	12 (WI) 2,005	14 (MI) 1,620	16 (MI) 1,834	21 (MI) 2,322	23 (WI) 2,002
Week						
1	97.0	77.4	97.9	94.8	98.2	82.8
2	92.8	67.7	95.2	25.3	16.6	0
3	0	55.9	89.0	2.8	2.5	
4		2.2	20.1	0.7	0.3	
5		0	4.2	0.4	0.2	
6			4.1	0.3	0.1	
7			3.8	0.2	0	
8			3.7	0		
9			3.7			

Table 3. Percent survival (weekly) of lake sturgeon fed Oregon Moist Pellets, under weaned and direct methods.

	OMP (weaned)			OMP (direct)		
Tank Source (N)	13 (WI) 2,180	15 (WI) 2,362	24 (MI) 1,979	6 (WI) 1,997	8 (WI) 2,000	22 (MI) 1,933
Week						
1	70.5	65.4	96.9	78.0	81.0	97.9
2	62.6	43.5	95.4	8.7	0	25.1
3	39.0	31.9	87.0	0		2.8
4	0.4	0	50.4			0
5	0.2		0.4			
6	0		0.2			
7			0			

6.92 mm/week). The three lots of Wisconsin sturgeon grew from 25.92 mm and 0.06 g to 88.31 mm and 2.55 g during that time (Tables 6 and 9). Growth rates among these fish also were not significantly different (ANCOVA, $P = 0.1432$; 8.18 mm/week). Differences between Michigan and Wisconsin sturgeon fed natural diets were found to be highly significant (ANCOVA, $P < 0.00005$) for the 9-week period.

Fish from one tank being fed an artificial diet (Biodiet weaned, Michigan sturgeon) survived for the duration of the study period and showed growth similar to Michigan sturgeon fed natural diets. Growth rates for the four lots of Michigan sturgeon (three natural and one artificial, Biodiet weaned) were found to be not significantly different (ANCOVA, $P = 0.2257$; 7.08 mm/week).

Because survival was very poor for many lots fed artificial diets, only lots with survival through week 5 were compared for differences in growth rates. This left only Michigan lots to be included in the analysis: 2 Biodiet direct, 1 Biodiet weaned, and 1 OMP weaned. The 2 lots of sturgeon fed Biodiet direct grew from 23.91 mm to 47.88 mm by the end of week 6 (Table 5). There were no significant differences in growth rates between these two lots (ANCOVA, $P = 0.3298$; 4.79 mm/week). Growth rates were significantly different between fish fed Biodiet weaned (7.61 mm/week, $P < 0.00005$) and OMP weaned (4.55 mm/week, $P = 0.0098$) (ANCOVA, $P = 0.0171$). Growth rates were also

Table 4. Mean total lengths (mm) each week for sturgeon raised under a variety of diets. Ninety-five percent confidence limits, as calculated using a pooled standard error from each treatment group, are given for those samples with n greater than one.

	Diet				
	Oregon Moist Pellet		Biodiet		Natural
Week	Direct	Weaned	Direct	Weaned	
1	24.59±0.59	26.48±0.59	24.34±0.60	25.42±0.59	26.18±0.59
2	28.13±0.62	27.11±0.59	28.50±0.60	26.76±0.59	28.68±0.59
3	28.66±0.64	28.59±0.59	29.53±0.60	29.23±0.60	38.91±0.59
4		33.33±0.61	35.06±0.64	37.99±0.61	46.10±0.59
5		41.60±0.83	42.45±0.67	50.06±0.62	52.31±0.59
6		50.33±1.29	47.88±0.69	56.66±0.62	61.24±0.59
7				62.66±0.62	69.07±0.59
8				74.26±0.62	75.89±0.59
9				81.84±0.59	84.31±0.59

Table 5. Mean total lengths (mm) each week for Michigan sturgeon raised under a variety of diets. Ninety-five percent confidence limits, as calculated using a pooled standard error from each treatment group, are given for those samples with n greater than one.

	Diet				
	Oregon Moist Pellet		Biodiet		Natural
Week	Direct	Weaned	Direct	Weaned	
1	24.10±0.62	27.00±0.62	23.91±0.60	25.03±0.60	26.45±0.60
2	28.13±0.62	28.43±0.62	28.50±0.60	26.73±0.60	28.73±0.60
3	28.66±0.64	28.93±0.62	29.53±0.60	27.66±0.62	37.34±0.60
4		32.13±0.62	35.06±0.64	38.13±0.62	44.74±0.60
5		41.60±0.84	42.45±0.67	50.06±0.62	50.57±0.60
6		50.33±1.29	47.88±0.69	56.66±0.62	58.07±0.60
7				62.66±0.62	64.01±0.60
8				74.26±0.62	72.99±0.60
9				81.84±0.60	80.31±0.60

Table 6. Mean total lengths (mm) each week for Wisconsin sturgeon raised under a variety of diets. Ninety-five percent confidence limits, as calculated using a pooled standard error from each treatment group, are given for those samples with n greater than one.

	Diet				
	Oregon Moist Pellets		Biodiet		Natural
Week	Direct	Weaned	Direct	Weaned	
1	24.84±0.60	26.22±0.60	25.20±0.62	26.20±0.62	25.92±0.60
2		26.45±0.60		26.83±0.62	28.64±0.60
3		28.43±0.60		30.80±0.62	40.49±0.60
4		37.33±0.69		37.00±0.95	47.46±0.60
5					54.05±0.60
6					64.49±0.60
7					74.14±0.60
8					78.80±0.60
9					88.31±0.60

Table 7. Mean weights (g) each week for sturgeon raised under a variety of diets. Ninety-five percent confidence limits, as calculated using a pooled standard error from each treatment group, are given for those samples with n greater than one.

	Diet				
	Oregon Moist Pellet		Biodiet		Natural
Week	Direct	Weaned	Direct	Weaned	
1	0.049±0.071	0.097±0.071	0.089±0.071	0.076±0.071	0.07±0.042
2	0.050	0.082±0.071	0.095±0.208	0.065±0.071	0.07±0.042
3	0.100	0.072±0.071	0.085±0.208	0.082±0.208	0.25±0.042
4		0.160±0.208	0.173±0.208	0.235±0.208	0.41±0.042
5		0.260	0.318±0.208	0.523	0.58±0.042
6		0.466	0.235±0.208	0.716	0.95±0.042
7				1.136	1.34±0.042
8				1.640	1.75±0.042
9				2.280	2.26±0.042

Table 8. Mean weights (g) each week for Michigan sturgeon raised under a variety of diets. Ninety-five percent confidence limits, as calculated using a pooled standard error from each treatment group, are given for those samples with n greater than one.

	Diet				
	Oregon Moist Pellet		Biodiet		Natural
Week	Direct	Weaned	Direct	Weaned	
1	0.043	0.181	0.063±0.208	0.066±0.208	0.07±0.071
2	0.050	0.056	0.094±0.208	0.083±0.208	0.08±0.071
3	0.100	0.100	0.085±0.208	0.070±0.208	0.22±0.071
4		0.120	0.173±0.208	0.220	0.40±0.071
5		0.260	0.318±0.208	0.523	0.53±0.071
6		0.466	0.235±0.208	0.716	0.83±0.071
7				1.126	1.17±0.071
8				1.640	1.61±0.071
9				2.280	1.96±0.071

Table 9. Mean weights (g) each week for Wisconsin sturgeon raised under a variety of diets. Ninety-five percent confidence limits, as calculated using a pooled standard error from each treatment group, are given for those samples with n greater than one.

	Diet				
	Oregon Moist Pellet		Biodiet		Natural
Week	Direct	Weaned	Direct	Weaned	
1	0.053±0.208	0.055±0.208	0.140	0.096	0.06±0.071
2		0.094±0.208		0.030	0.06±0.071
3		0.058±0.208		0.093	0.27±0.071
4		0.200		0.250	0.42±0.071
5					0.63±0.071
6					1.07±0.071
7					1.58±0.071
8					1.89±0.071
9					2.55±0.071

significantly different between fish fed Biodiet weaned and fish fed Biodiet direct (ANCOVA, P = 0.0022).

The relationship between body length and body weight for the six lots of sturgeon fed natural diets is provided in Figure 2. Further, Figure 2 shows the length-weight relationship over the 9-week study was similar among juvenile Michigan and Wisconsin sturgeon.

Thus, the major result of the feeding experiments is that of those diets tested, natural diets were far superior to the artificial diets in promoting survival and growth in juvenile lake sturgeon. Data from lots that did not survive through the fifth week of the study are not included in the above evaluation of diet effects on growth. However, consideration of mean number of weeks for which lots showed any fish surviving, together with mean growth rates for those lots surviving at least through the third week, may indicate the relative effectiveness of the diet types and methods used in this study. Of the two artificial diets tested, Biodiet consistently showed higher survival and mean growth rates than fish fed OMP (Table 10). When comparisons are made between sturgeon fed according to the weaned and direct methods, the weaned method appears to have promoted higher survival, and in one lot of Michigan fish fed Biodiet weaned, growth rates were similar to those observed for Michigan fish fed natural diets. Generally, lots of fish fed artificial diets under the direct method had poor

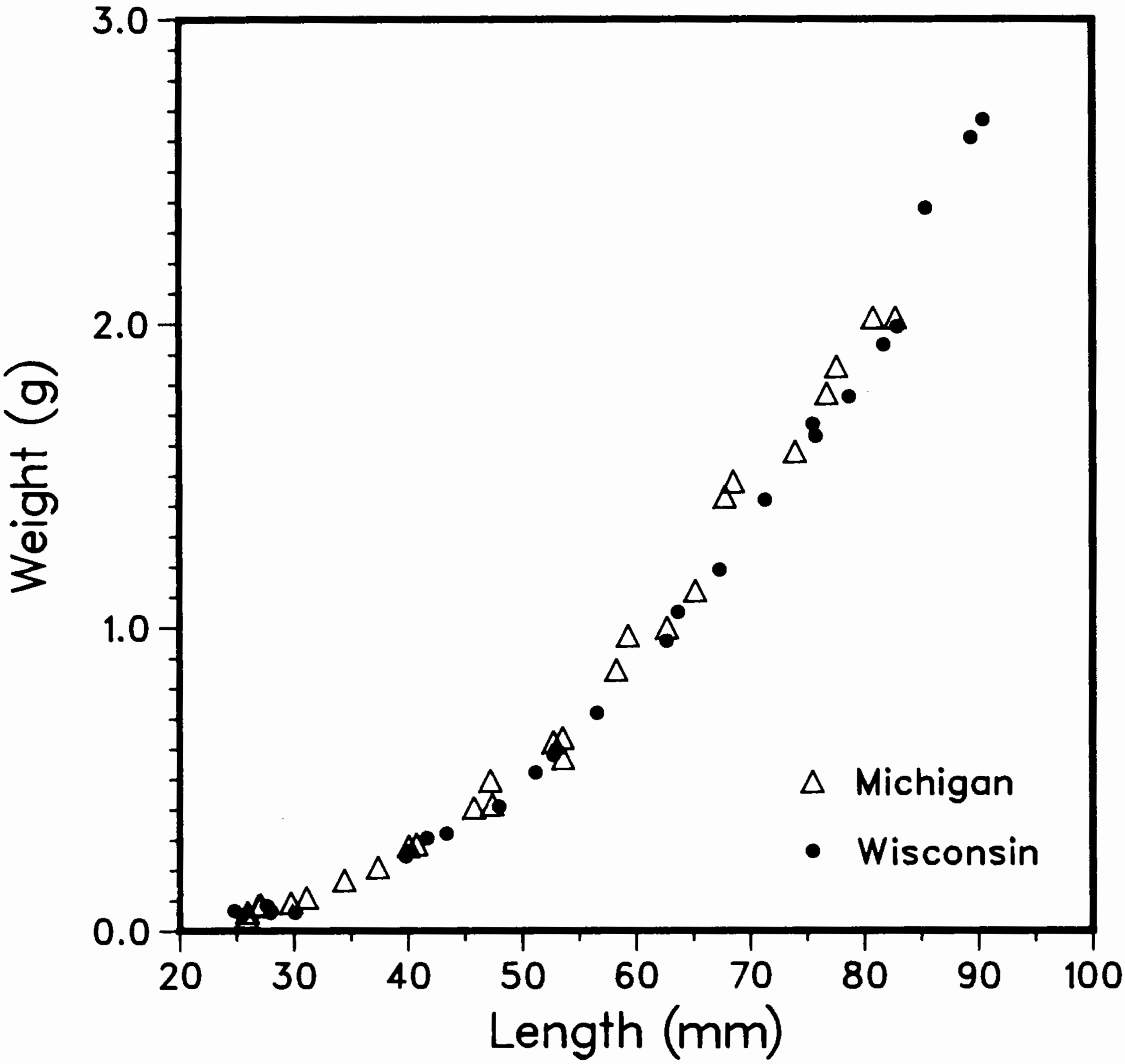

Figure 2. The relationship between mean body length (L) in mm and mean body weight (W) in g for Michigan and Wisconsin sturgeon from individual lots fed natural diets throughout the 9-week study.

survival and decreased growth rates relative to fish fed according to the weaned method.

Table 10. Mean values for survival (weeks) and growth rates (mm/week) for all lots of sturgeon fed a variety of artificial diets. Growth rates are from only those sturgeon that survived at least through the third week of the study period.

Diet	Biodiet		OMP	
Method of feeding	Survival in weeks	Growth rate mm/week	Survival in weeks	Growth rate mm/week
Direct	4.67	4.79	2.00	2.28
Weaned	5.00	5.63	4.67	3.05

DISCUSSION

The effects of two artificial diets (OMP and Biodiet) and a natural diet (zooplankton and aquatic annelids) and feeding techniques on survival and growth were evaluated for hatchery-reared lake sturgeon to explore the possibility of a continued cultural program in Michigan. Eggs and milt were collected from spawning adults, fertilized, hatched, and reared to a plantable size. Overall, sturgeon fed natural diets survived and grew well, as expected from previous studies (Binkowski 1980). In contrast, sturgeon fed artificial diets generally did not survive or grow well (also see Binkowski and Czeskleba 1980).

Survival

Survival of lake sturgeon was greater than 45% at the end of the study for all six lots of sturgeon fed natural diets. Of these, Michigan sturgeon consistently had higher survival than Wisconsin sturgeon in the initial weeks of the study, and a higher total survival during the 9-week study period (Table 1). The differences in initial mortality appear to account for the differences in overall mortality (Tables 1 to 3), suggesting experimental fish were differentially responding to handling or conditions of newly assigned tanks rather than the diets presented during the study.

In contrast, survival of lake sturgeon fed artificial diets was very poor (Tables 2 and 3). Comparisons between these lots are restricted to those that showed some survival through the fifth week of the study, which leaves 4 lots of Michigan fish. Only 1 of the 12 lots fed artificial diets had survivors by the end of the study period (Table 2). Thus, a Michigan lot fed Biodiet weaned showed 3.7% survival after 9 weeks. This alone suggests that Biodiet weaned may be the most effective artificial diet tested here. However, the lot that survived through week 9 was the only one of three lots fed Biodiet weaned that had any survival (only 3.7%) past the fourth week. Fish fed Biodiet direct and OMP weaned had no survivors by the eighth week of the study

(Tables 2 and 3). It thus appears that of the artificial diets tested, Biodiet weaned may be the most effective for rearing sturgeon to a plantable size.

Growth

Growth rates (calculated as changes in length over time) were compared among experimental fish to further examine the effect of different diets. As done for survival effects, only those lots of sturgeon that survived through the fifth week of the study were included in these comparisons.

Michigan and Wisconsin sturgeon fed natural diets exhibited strong growth throughout the 9-week study period. Growth rates of Michigan and Wisconsin sturgeon fed natural diets were 6.92 mm/week and 8.18 mm/week, respectively, similar to those reported for successfully cultured white sturgeon (*Acipenser transmontanus*) (Monaco et al. 1981). The only lot fed an artificial diet (Biodiet weaned) that survived throughout the study also showed strong growth in those that survived (3.7% of the initial number). The growth rate for this lot was not significantly different from Michigan fish fed natural diets (P = 0.2257). The other lots fed artificial diets showed much poorer growth. Thus, fish fed Biodiet direct grew about 4.8 mm/week and fish fed OMP weaned grew about 4.6 mm/week.

Culture schemes

The advantages of using an artificial diet to culture fish are reviewed by Hublou et al. (1959). Many cultured fish can now be reared entirely or partially on artificial diets without supplementary natural diets at a particular stage in their life (Hastings and Dickie 1972). The majority of cultured species that accept these diets are either carnivores or omnivores (Ghittino 1972). Salmonids are cultured extensively and reared entirely on artificial diets. First-feeding larvae are most commonly fed a semi-moist "starter" diet, such as Biodiet, and are progressively moved to larger pellets as the fish grow. There are many species of fish that require a natural diet during the first portion of their life that can be directly switched or weaned to an artificial diet at a certain size. For example, striped bass (Morone saxatilis) require natural diets during early life stages before being weaned to artificial diets (Lewis and Heidinger 1981).

This study demonstrates lake sturgeon can be successfully reared from eggs under hatchery conditions if fed natural diets. Further, lake sturgeon do not accept the artificial diets used here if presented at the time of yolk-sac absorption (direct method) or if accompanied by natural diets for an additional 15 days (weaned method).

In other experiments, researchers have been successful in weaning small numbers of lake sturgeon onto Biodiet after the fish were approximately 150 to 180 mm in length (Kim Graham, Missouri Department of Conservation, personal communication). Experiments conducted by Monaco et al. (1981) have produced similar results for white sturgeon fed OMP; however, only a small percentage (20-30%) accepted the diet. Copeland (1970) experimentally fed OMP to a small number of lake sturgeon and was unsuccessful at rearing them on this diet. A number of the other artificial diets have been tested on lake sturgeon by Binkowski (1980), with limited success.

The successful culture of several species of sturgeon using ponds is well established in the Soviet Union (Bardach et al. 1972). Sturgeon culture in North America, however, remains largely experimental (Buckley and Kynard 1981; Smith et al. 1980). The few attempts to utilize pond culture to raise lake sturgeon have been unsuccessful, probably due to high temperatures and an overabundance of aquatic macrophytes, rather than limited food since zooplankton was available (Copeland 1970, Czeskleba 1979). These possibilities can be readily evaluated. The problem of rearing lake sturgeon on artificial diets is yet to be solved as the sturgeon do not accept the currently available pellets well. Additional work is needed to more fully explore the potential for rearing lake sturgeon on artificial diets.

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